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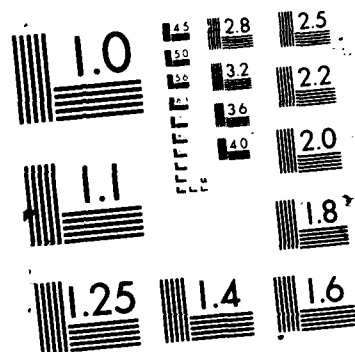
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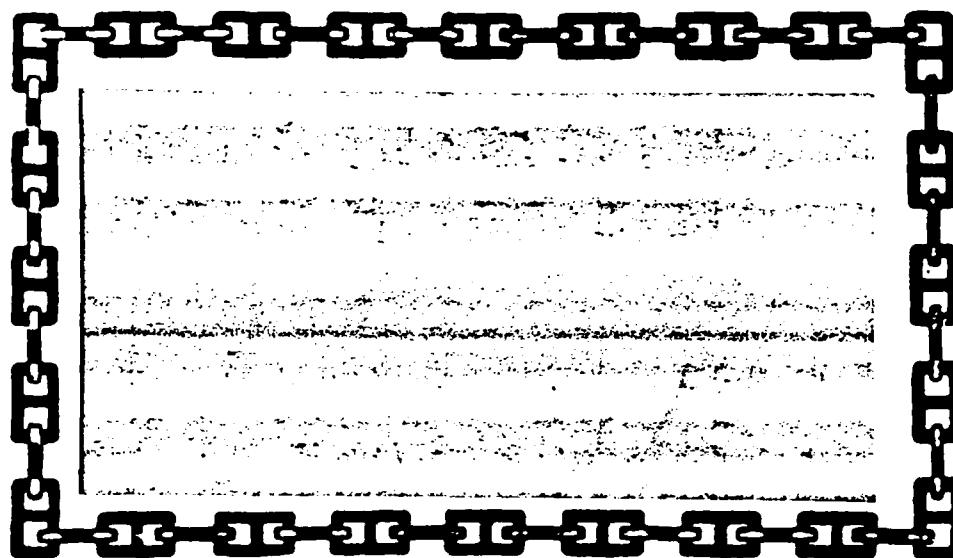
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MK 15 MOD 0 ALTERNATE CARBON DIOXIDE

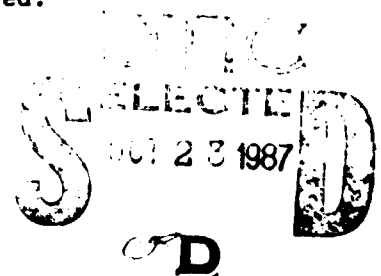
ABSORBENT MATERIALS

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ABSTRACT

A comparative study of Draegersorb, LimePak and HP Sodasorb carbon dioxide absorbents within the MK 15 Mod 0 Underwater Breathing Apparatus (MK 15) was performed at the Navy Experimental Diving Unit. Draegersorb and LimePak appeared to be marginally more effective than HP Sodasorb. However, their usefulness to extend the MK 15 canister duration may be limited because of the wide variability of time to reach the arbitrarily determined canister breakthrough of 3.8 mmHg CO₂ (0.5% SEV) though the oxygen consumption rates were similar, \dot{V}_{O_2} 1.1 l/min. The polypropylene moisture absorbent pads are a suitable replacement pad for the MK 15 and can be reused.

KEY WORDS:

NEDU Test Plan 87-01
NAVSEA Task No. 87-04
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Oxygen Consumption
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I. INTRODUCTION

The MK 15 Mod 0 (MK 15) is a closed circuit mixed gas SCUBA which maintains a constant partial pressure of oxygen of 0.7 atmospheres absolute (ATA). Air is used as the diluent gas. Initial certification of the diving apparatus used High Performance (HP) Sodasorb (W. R. Grace Co., Atlanta, GA) as the carbon dioxide (CO₂) absorbent material. Previous manned testing of the MK 15 showed the canister duration limited to 2 hrs in 2°C (35°F) water (1). No other absorbent materials were tested. Since then unmanned data suggested the other CO₂ absorbents were equal to or exceeded the performance of HP Sodasorb (2).

This manned study measured the MK 15 canister duration times of a moderately working diver, as defined by the oxygen consumption rate, for the alternate CO₂ absorbent materials. The different absorbent materials included LimePak (Rexnord Breathing Systems, Malvern, PA), Draegorsorb (Draegerwerk AG, Lubeck), and HP Sodasorb. Identifying suitable alternate absorbents can increase mission capability since the users would no longer be restricted to one source.

In addition, a problem with the foam moisture absorbent pads was previously identified, NEDU Report 9-86. The pads deteriorate rapidly, even after one use. Degradation of the pads can alter the performance of the carbon dioxide absorbent canister by allowing the diver's saliva to cake the soda lime. Thus, a pad that resists deterioration should maintain the efficiency of the CO₂ scrubber. An additional benefit of a such a multi-use pad would be to lower the logistical requirement for the MK 15. Unmanned testing at NEDU of wet polypropylene moisture absorbent pads showed lower peak to peak differential pressure and breathing work than the current foam pads. In addition, after soaking the polypropylene pads in a mixture of CO₂ absorbent material and salt water there was no degradation (6). This current manned study included an evaluation of these pads.

II. METHODS

Divers

Nine U.S. Navy divers trained in the MK 15 participated as subjects. The dives were conducted during a 7-day, 60 feet of seawater (FSW) Air Saturation Dive within the Ocean Simulation Facility (OSF) wet chamber at the Navy Experimental Diving Unit (NEDU) as per NEDU Test Plan 87-01. Simulated diver depth was approximately 65 FSW. Water temperature was $2 \pm 1^\circ\text{C}$ (35°F). Thermal protection of the divers consisted of a Viking Dry Suit with Thinsulate® 600/800 undergarments which included a dry hood and gloves.

Work Schedule

Four specially designed pedal mode ergometers were calibrated (3) and adjusted to a 37° heads-up position. The ergometers were placed so that the divers' mid-chest was 5 feet below the water line within the wet chamber.

Only three ergometers were used at one time; the fourth was available in the event of a failure. Three divers exercised simultaneously at a surface indicated work load of 50 watts, 55-65 RPM, on a 6 minute work, 4 minute rest schedule. This schedule was continued until the canister effluent reached 11.4 mmHg (1.5% SEV) CO₂. When necessary during the dive, the diluent bottle, oxygen bottle, or primary battery was replaced. Data recording was not interrupted during changes. The divers were rotated every 2-3 hrs to minimize diver fatigue and thermal stress.

MK 15

Each MK 15 was set up at 1.0 ATA according to the MK 15 Mod 0 UBA Operations and Maintenance Manual (NAVSEA 0994-LP-016-1010). A fresh, fully-charged magnesium alkaline battery was used for each dive. The canisters were freshly packed and weighed using the same batch of either Draegersorb, LimePak, or HP Sodasorb. The different CO₂ absorbents main component is soda lime. The major difference is the grain mesh size. Draegersorb and LimePak grain size is smaller, 8-12 mesh, compared to HP Sodasorb which is 4-8 mesh. The canister weight was recorded pre and post dive. The diluent gas was approximately 76/24% nitrogen-oxygen. This mixture was chosen to provide diluent gas with an oxygen partial pressure of 0.7 ATA at the test depth. Thus, any oxygen lost from the MK 15 due to mask clearing, gas sampling, etc., would be made up from the diluent bottle and not the oxygen bottle. This method allows calculating the oxygen consumption without having to account for gas loss (4).

Each MK 15 moisture absorbent pad was made with Duon® polypropylene non-woven fabric (Phillips Fibers Corporation, Greenville, S.C.) that have been form cut by Rexnord Breathing Systems. Immediately after surfacing the MK 15, photos were taken to document the amount of spittle that accumulated during the 5 to 6 hr N₂O₂ dive. The moisture pads were visually inspected for signs of deterioration.

The oxygen bottle pressure was measured with a Validyne DP 15 Pressure Transducer equipped with a 3000 psig \pm 1% diaphragm or a Druck PTX 160/D 0-5000 psig pressure transducer mounted to the MK 15 oxygen high pressure line. Calibration from 0-2500 psi was done using a Mensor 11600 digital pressure gauge (2500 psi \pm 0.04%). The linear regression of the pressure transducer voltage vs the digital pressure gauge reading was calculated by an HP-1000 computer (Hewlett Packard, Cupertino, CA). A plot of oxygen bottle pressure vs time was made from which oxygen consumption was estimated using the following formula (4):

$$\dot{V}_{O_2} = (\Delta P/T) \cdot V_b \cdot [273/(T + 273)]$$

where:

$$\dot{V}_{O_2} = O_2 \text{ consumption (slpm)}$$

$$\Delta P/T = \text{slope of } O_2 \text{ pressure plot (ATA/min)}$$

$$V_b = O_2 \text{ bottle floodable volume (approximately 2.8\ell)}$$

$$T = O_2 \text{ bottle temperature (assumed equal to the wet pot temperature } ^\circ\text{C)}$$

Canister Duration

One gas sample line for the canister effluent was attached to the MK 15 inhalation breathing hose. A Perkin Elmer MGA 1100 mass spectrometer was used to analyze for CO_2 to each diver. A reading was taken every 30 seconds and recorded on the HP 1000 computer. The mass spectrometers were calibrated prior to each canister study and checked every 30 min during the study. Breakthrough had been arbitrarily chosen to be 3.8 mmHg (0.5% SEV) CO_2 . The MK 15 canister durations were determined when the canister effluent sustained 3.8 mmHg CO_2 for at least one minute. Experience shows that there is a rapid rise in effluent CO_2 when breakthrough is reached. The study was continued to 11.4 mmHg CO_2 to further define the canister's characteristics.

III. RESULTS

Using Draegersorb the canister lasted 280 ± 70 minutes before breakthrough. LimePak went for 287 ± 42 minutes whereas the HP Sodasorb filled canister reached breakthrough in 250 ± 19 minutes. The results are summarized in Table 1.

Oxygen consumption rates were used to compare the actual work rates performed by the diver-subjects. In this study the overall \dot{V}_{O_2} for all runs ranged between 1.00 - 1.18 ℓ/min . STP.

Inspection of the canister holder revealed large amounts of frothy secretions in eight of the fifteen MK 15s after the 5 to 6 hour dives. Inspection of the polypropylene pads did not show any signs of degradation after three uses.

IV. DISCUSSION

Preliminary unmanned data suggested the other CO_2 absorbents, LimePak and Draegersorb, out-performed HP Sodasorb (2). However, the present study suggests that Draegersorb and LimePak are similar in performance to HP Sodasorb in the MK 15. Though Draegersorb and LimePak had runs that suggested

a greater affinity for carbon dioxide removal, the large deviations from the mean reduce the time for a safe operating canister duration. A safe operational limit may be derived by subtracting one standard deviation from the mean time to reach canister breakthrough (1). Assuming our diver-subjects represent a normal population of MK 15 divers subtracting one standard deviation allows us to prescribe limits that the majority of divers can safely use. Thus the operational limit for Draegersorb is 210 min., LimePak 245 min. and HP Sodasorb 231 min. when the oxygen consumption rate is 1.09 l/min. STP.

The wide variance of performance was not seen with HP Sodasorb for the three dives in this study. Previous manned studies using HP Sodasorb did show wide variance (1, 5). However, those studies had an oxygen consumption rate of 1.4 l/min vice this study's rate of 1.09 l/min. Therefore, the only conclusion that can be made is that Draegersorb and LimePak are at least as effective as HP Sodasorb.

During the work cycle the breathing resistance, as subjectively noted by the divers, appeared to increase as the canister CO₂ effluent approached 3.8 mmHg, canister breakthrough. As the level of CO₂ surpassed breakthrough, divers reported using the diluent bypass valve in an effort to increase gas flow and reduce the breathing effort. One diver reported that "it was harder to breathe than to pedal the bike". Further testing is necessary to delineate the cause of the dyspnea. The possibilities include caking of the small grain CO₂ absorbent by moisture from the diver resulting in increased breathing resistance or from the direct effect of elevated CO₂ levels.

The cycle of 6 min work with the bicycle ergometer set at 50 watts and 4 min rest has been the standard method to obtain similar work rates between divers and dives. The goal of this method was to produce a $\dot{V}O_2$ of 1.3-1.6 l/min to simulate an underwater swimmer swimming at 0.8 knots (6). However this study produced lower oxygen consumption rates. During the dive the ergometers were tested and verified that the electric brake loaded when the wattage was increased. The ergometer post dive calibration check showed only a drop of 2 to 3 computed force watts at a 50 watt load setting. The lower than expected oxygen consumption rate, therefore, was not due to the bicycle ergometer.

The assumption has always been made that pedaling the ergometer underwater added 25-50 watts to the diver's work load indicated on the ergometer's control box. The increased load probably is due to a combination of fluid resistance, suit drag, and suit inflexibility (4, 5). Studies at NEDU suggest that using the same work protocol produces different work loads depending on the type of diver dress. The less restrictive dress allowed an increase in divers' mobility. This ease of motion, and therefore less work performed by the diver, was reflected by a lower $\dot{V}O_2$. This study used a different diver dress than the previous MK 15 manned studies. Former studies used the Passive Diver Thermal Protection System (PDTPS) which uses a specially processed neoprene elastomer outergarment, 3/4 inch closed cell neoprene, over Thinsulate® underwear. In contrast, this study used the Viking Dry Suit, which uses a thin outergarment over the Thinsulate® underwear.

Since the undergarments were the same, it can be assumed that the characteristics of the outer garment account for the differing work levels. The thickness and relative inelasticity of the PDTPS restricts the movement of the diver. Thus, the diver has to work harder to overcome the resistance of the PDTPS compared to the Viking Dry Suit.

V. CONCLUSIONS

Draegersorb and LimePak are viable alternatives for HP Sodasorb. They are at least as effective as HP Sodasorb. At present it is unlikely that the use of these carbon dioxide absorbents can improve the MK 15 canister duration limits.

Polypropylene moisture absorbent pads are effective replacements for the MK 15 foam moisture absorbent pads. They resist degradation with multiple use which is in contrast to the foam pads. Therefore, the polypropylene pads can be reused until there is evidence of deterioration.

The reported increased breathing resistance when the canister effluent approached breakthrough needs to be investigated. Dyspnea is due to elevated CO₂ levels and/or increased breathing resistance due to the absorbent materials can seriously compromise divers and their missions.

Oxygen consumption rates produced on an underwater bicycle ergometer vary with the divers' thermal protection garment. This variance must be more accurately factored into future carbon dioxide absorbent canister testing.

TABLE 1
DRAEGERSORB
(Grain Size 8-12 mesh)

Pre-Dive Canister Weight: 4.5 kg (10 lbs)
Range: 4.4 to 4.5 kg

V_{O_2} l/min.	Minutes to 3.8 mmHg CO_2	Minutes to 11.4 mmHg CO_2
1.11 ± .07	340	389
1.11 ± .06	234	337
1.12 ± .15	318	390
1.06 ± .09	364	412
1.13 ± .06	192	360
<u>1.05 ± .05</u>	<u>232</u>	<u>298</u>
Mean ± S.D. 1.10 ± .03	280 ± 70	364 ± 42

LIME PAK
(Grain Size 8-12 mesh)

Pre-Dive Canister Weight: 4.4 kg (9 lbs 12 oz)
Range: 4.2 to 4.4 kg

V_{O_2} l/min.	Minutes to 3.8 mmHg CO_2	Minutes to 11.4 mmHg CO_2
1.08 ± .15	296	397
1.08 ± .08	344	427
1.14 ± .12	238	296
1.18 ± .11	237	306
1.04 ± .12	297	374
<u>1.00 ± .08</u>	<u>313</u>	<u>414</u>
Mean ± S.D. 1.09 ± .03	287 ± 42	369 ± 56

HP SODASORB
(Grain Size 4-8 mesh)

Pre-Dive Canister Weight: 4.0 kg (9 lbs)
Range: 3.9 to 4.1 kg

V_{O_2} l/min.	Minutes to 3.8 mmHg CO_2	Minutes to 11.4 mmHg CO_2
1.06 ± .11	296	397
1.10 ± .10	344	427
<u>1.11 ± .05</u>	<u>313</u>	<u>414</u>
Mean ± S.D. 1.09 ± .03	287 ± 42	369 ± 56

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